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THE CONTROL OF PNEUMONIA AND INFLUENZA BY THE WEATHER

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1. THE NEW TREATMENT OF RESPIRATORY DISEASES

The revolutionary changes of the last few decades in the treatment of tuberculosis may be the precursors of an even more drastic revolution in the treatment not only of tuberculosis, but of pneumonia, influenza, and other respiratory diseases. The principle of the new tuberculosis treatment is the purely ecological idea that the respiratory system requires outdoor air. The logical expansion of this principle is that the best treatment for all kinds of respiratory diseases is air that is ideal in all respects. Aside from light and purity, the three most important atmospheric conditions are (1) temperature, (2) relative humidity, and (3) variability and movement. The old indoor treatment of tuberculosis was a failure largely because it centered entirely around temperature. The new outdoor treatment—although most people do not recognize this—centers around variability and movement with only incidental attention to temperature and humidity. The treatment of the future will presumably pay equal attention to all three factors.

The first step toward this new treatment is a statistical analysis of the relation of ordinary air to health. Hence the present paper is an attempt to find out what are the ideal atmospheric conditions for patients suffering from pneumonia and influenza.

2. RELATION OF TEMPERATURE TO PNEUMONIA AND INFLUENZA

To begin with temperature, Greenburg[1] has taken the monthly figures for deaths from lobar pneumonia in New York, Boston, Newark, and Providence for a series of years, and has compared them with the mean temperature of the corresponding months by means of "climographs." He finds that deaths from pneumonia have a direct relation to the outside temperature, and decrease systematically as the temperature rises. Shaw[2] states that in England the same rule applies to influenza under ordinary circumstances.

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[1] David Greenburg, "Relation of Meteorological Conditions to the Prevalence of Pneumonia," Journal of American Medical Association, 1919, p. 252.

[2] Napier Shaw, Quarterly Journal, Royal Met. Soc., Vol. XLV, July, 1919. (In discussion of article on Atmospheric Conditions which Affect Health, by Leonard Hill.)

In order to test the matter in another way, I have taken the day instead of the month as the unit, and have tabulated the deaths from lobar and broncho pneumonia according to temperature, as appears in Table 1.

TABLE 1. *Average daily deaths from pneumonia at various mean temperatures in New York City, from April, 1917, to March, 1918*

Mean Temp. Fahrenheit . .	20° or less	21°–32°	33°–45°	46°–55°	56°–65°	66°–70°	71°–75°	Over 75°
Lobar pneumonia . . .	26.5	26.4	27.8	20.6	17.4	9.4	6.3	6.7
Broncho pneumonia .	8.3	9.6	8.2	6.2	5.4	3.9	2.5	3.3
No. of days	(30)	(47)	(72)	(70)	(51)	(31)	(38)	(26)

The general decline in the deathrate with rising temperature is obvious. From 33° to 75° it is highly systematic. At the lowest temperatures there is a little irregularity, due to the fact that a mild epidemic doubled the deathrate for a couple of weeks at the end of March. In view of the lateness of the season at which this occurred, it is surprising that the deathrate at temperatures of 33–45° has not been raised much higher. In ordinary years the realtion between low temperature and the deathrate wolud be even stronger than appears in Table 1. At the right-hand end of the table, a slight increase in deaths is apparent at high temperatures above 75°. Judging by more abundant statistics for other diseases, this is a constant characteristic, and means that high temperatures as well as low are bad for pneumonia.

As a test of Shaw's conclusion that influenza as well as pneumonia varies inversely as the temperature, I have used the weekly figures for deaths from influenza in New York City during the thirty years from 1889 to 1918. These are summed up in Figure 1, where the solid line shows the average weekly deathrate from influenza omitting the great epidemics of 1891 and 1918, but including the minor epidemics. It is noticeable that deaths from influenza begin toward the end of September at about the time when the nights first become frosty. The deathrate suddenly increases about the middle of December at approximately the time when the mean temperature falls below freezing. It reaches a maximum a little after the middle of January, just at the time when the cold weather also reaches a maximum. Thereafter the disease declines, the decline being regular at first for a month, but then becoming irregular because of epidemics. If these epidemics were eliminated, it seems probable that the deathrate would follow the dash line in Figure 1, and be reduced to zero at about the time when the frosts come to an end. However this may be, it is quite clear that aside from the two great epidemics, influenza begins with the frost; becomes severe when the temperature averages below freezing; reaches a maximum when the weather is coldest; and then declines.

The dotted lines in Figure 1 show how the average weekly deathrate for

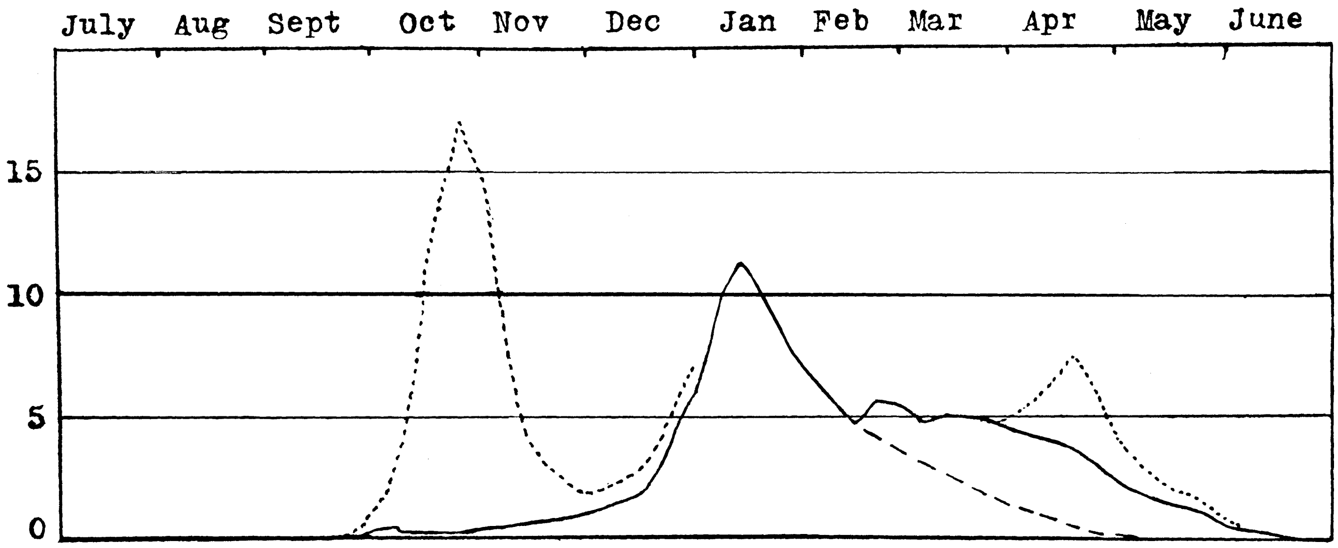

Fig. 1. Weekly deathrate per million from influenza in New York City from 1889 to 1918. Solid line indicates deathrate omitting the epidemics of 1891 and 1918. Dotted line indicates deathrate when these two epidemics are included. Dash line indicates probable deathrate if other epidemics were omitted.

the thirty years is modified if the two great epidemics are included. We shall return later to the contrast between the epidemic and endemic forms of influenza. For the present it is enough to see that the endemic form and even the milder epidemics in New York agree with Shaw's conclusion as to the marked effect of low temperature in increasing the severity of influenza.

3. Relation of Humidity to Pneumonia and Influenza

Let us now turn to humidity. In all the investigations of pneumonia except Greenburg's, relative humidity has been omitted or has played a minor rôle. Greenburg, however, find that the amount of moisture in the air is of the highest importance, for at all temperatures there are fewer deaths when the relative humidity is high than when it is low. The daily deaths in New York City from April, 1917, to March, 1918, lead to the same conclusion, but give an important emphasis to certain temperatures. This appears in Table 2.

The first section of the table, headed "Weather Conditions," shows that here, as in Table 1, the days of the year have been divided into eight groups according to temperature. Each group has again been divided into two divisions: (I) days with low relative humidity, and (II) days with high relative humidity. For temperatures below 65° the dividing line has been a humidity of 60 percent, while for higher temperatures, in order to make the number of days in the two sections more nearly equal, it has been 70 percent. Section 2 shows the number of deaths per day from lobar pneumonia on the day when the given weather conditions prevailed. In each of the eight temperature groups, the days with a high relative humidity have an advantage, as appears in the line labelled "Advantage of II over I." This ranges from 0.8 percent up to 26.8 percent. In Section 3 similar figures are given for the number of deaths on the day *after* the given weather conditions. Here, just as in Section 2, the days with high relative humidity have a decided advantage. In other words, no matter what the temperature, the deathrate from lobar pneumonia during the year in question was less when the humidity was high than when it was low.

The reader may ask whether the apparent effect of humidity may not be really due to temperature. This is answered in the next to the bottom line of Section 1, which shows that in six groups out of eight the difference between the temperature of the days with high and low humidity is only about one degree. The two exceptional groups are the coldest and the warmest. In the cold group the days with high humidity were 3.2° F. colder than those with low humidity, which would tend to make the deathrate of the more humid days higher than that of the others instead of about 7 percent lower, as is actually the case. Apparently a little extra moisture more than overcomes the bad effects of a few degrees of cold. Turning to the warmest group, we find a different state of affairs. Extremely high temperature, as

TABLE 2. *Daily deaths from pneumonia in relation to temperature and humidity, New York City, April, 1917, to March, 1918*

Section 1. Weather Conditions

Mean temperature	20° or less	21–32°	33–45°	46–55°	56–65°	66–70°	71–75°	76° or more
I. Days with Low Rel. Humidity:								
A. Av. Temp.	13.9°	27.1°	38.9°	49.8°	61.0°	68.1°	72.8°	79.4°
B. Av. Rel. Hum.	50.9 %	52.6 %	50.6 %	48.2 %	49.2 %	57.6 %	57.0 %	64.0 %
C. No. of Cases	16	31	38	38	21	16	21	15
II. Days with High Rel. Humidity:								
A. Av. Temp.	10.7°	27.8°	39.7°	49.6°	60.4°	66.8°	73.1°	77.1°
B. Av. Rel. Hum.	71.1 %	78.1 %	72.4 %	73.7 %	76.4 %	82.5 %	78.0 %	77.9 %
C. No. of Cases	14	17	34	33	30	15	17	11
Excess of II over I:								
A. Temp.	−3.2°	0.7°	0.8°	−0.2°	−0.6°	−1.3°	−0.3°	−2.3°
B. Rel. Hum.	20.2 %	25.5 %	21.8 %	25.5 %	27.2 %	24.9 %	21.0 %	13.9 %

Section 2. Deaths per Day from Lobar Pneumonia on *Same* Day as Given Weather Conditions

I. Low Relative Humidity	27.5	26.5	28.2	22.4	20.3	10.6	6.7	6.8
II. High Relative Humidity	25.4	26.3	27.3	18.4	15.9	8.1	5.9	6.5
Advantage of II over I	7.6 %	0.8 %	3.2 %	17.8 %	21.6 %	23.6 %	26.8 %	4.4 %

Section 3. Deaths per Day from Lobar Pneumonia on Day *After* Given Weather Conditions

I. Low Relative Humidity	29.3	26.8	29.2	20.6	19.3	10.4	6.2	6.7
II. High Relative Humidity	27.2	25.5	28.6	19.2	14.3	8.2	6.2	6.5
Advantage of II over I	7.2 %	4.9 %	2.1 %	6.8 %	25.9 %	21.2 %	0.0 %	3.0 %

Section. 4. Deaths per Day from Broncho Pneumonia on *Same* Day as Given Weather Conditions

I. Low Relative Humidity	9.4	9.2	7.7	6.4	5.9	3.6	2.6	3.7
II. High Relative Humidity	8.8	10.2	8.7	6.0	5.0	4.2	2.4	2.8
Advantage of II over I	6.4 %	−10.9 %	−13.0 %	6.2 %	15.3 %	−16.7 %	7.7 %	24.4

Section 5. Deaths per Day from Broncho Pneumonia on Day *After* Given Weather Conditions

I. Low Relative Humidity	10.0	9.8	7.3	6.3	5.9	4.0	2.8	3.3
II. High Relative Humidity	8.9	9.6	7.9	6.1	5.0	4.1	2.7	2.9
Advantage of II over I	11.0 %	2.0 %	−8.2 %	3.2 %	18.0 %	−2.5 %	3.6 %	12.1 %

we have already seen, is harmful. Thus the days with high humidity have an advantage of 2.3° in temperature when compared with the dry days. Nevertheless, their deathrate is less by only 4.4 percent in Section 2 and 3.0 percent in Section 3. This slight advantage is probably due entirely to the lower temperature of the moister days, and it is doubtful whether high humidity is any advantage in such warm weather. From other lines of evidence such as operations, we infer that high humidity and extremely low humidity are about equally harmful at high temperatures.[3] The best condition is intermediate.

4. Divergent Humidity Relations of Lobar and Broncho Pneumonia

Turning now to Sections 4 and 5 of Table 2 we find that humidity appears to be of much less importance in broncho pneumonia than in the lobar type. Not only is there a good deal of irregularity in the numbers showing the advantage of moist over dry days, but five out of sixteen of the numbers are negative. Doubtless much of this irregularity is because the deaths from broncho pneumonia numbered only 2,400 against 7,200 from lobar pneumonia. It seems likely, however, that there is a real difference between the two types of pneumonia, and that in the more severe and deep-seated form proper humidity is much more important than in the milder type. Nevertheless, the weighted average of all the groups of broncho pneumonia as given in Sections 4 and 5 shows that the days with higher humidity have an advantage of about 2 percent over the drier days.

5. Effect of Humidity at Indoor Temperatures

By far the most significant part of Table 2 is the two groups of days having temperatures of 56–65° and 66–70°. Such temperatures represent the conditions which prevail at all times within doors. Therefore, it seems justifiable to use them as a criterion of the actual effect of humidity upon patients. In lobar pneumonia the advantage of the days with high humidity at these temperature averages 23 percent, while even in broncho pneumonia the weighted average for sections 4 and 5 amounts to an advantage of about 7 percent for the days with the higher humidity. These figures go far toward indicating that a considerable part of the harm usually attributed to low temperature is really due to the low humidity which prevails within doors when the outside air is cold. When the outside air averages 55–70° and the relative humidity is above 70 percent. the deathrate from lobar pneumonia for the period under discussion remains fairly constant at about 11. At the same temperatures, if the humidity is between 40 and 50 percent, the daily deathrate rises to 17.8, or to about 14.5 if allowance is made for certain exceptionally warm days in early spring when the winter deathrate still prevailed. In other words, as long as the humidity remains above 70 percent or possibly 65 percent, the deathrate remains at a rather uniform and comparatively low level. A further drop of about 20 percent in humidity, however, causes an increase of at least a third in the deathrate.

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[3] Huntington, Ellsworth, "Air Control and the Reduction of the Deathrate after Operations," Modern Medicine, Oct. and Nov., 1919, pp. 463–468, 555–558.

During the winter the air in the average house in New York has a relative humidity of only about 30 percent, while the deaths from lobar pneumonia number about 27 or 28 per day for the year under discussion. Suppose now that during the warm weather when the outside air averages 55–70°, the humidity were to be as low as in our winter houses. Apparently the pneumonia deathrate would increase by at least a third and perhaps one half over what it is in such weather when the humidity is 70 percent or more. Of course a far larger body of figures is needed before we can determine the exact effect of any given condition, but the principle seems clear. Apparently we are killing people by the thousand simply because we do not properly humidify the air in our hospitals.

It would be well if the method of Table 2 could be applied not only to pneumonia for many years, but also to influenza and many other diseases. On account of the lack of data for influenza except during the epidemic, however, this is at present impossible. Nevertheless, deaths from influenza and lobar pneumonia follow so closely the same course that it seems probable that conditions which are bad in one case are also bad in the other.

6. Relation of Variability in Temperature to Pneumonia

We come now to the relation between disease and the variability of the weather, a subject as to which there is almost no reliable information. Yet there appears to be a close relationship, as is indicated in Table 3. In this table the same data have been used as in Tables 1 and 2, namely, the daily deaths from lobar and broncho pneumonia for a year in New York City. Instead of employing the absolute number of deaths, however, the *change* from one day to the next has been taken, in order that the greater frequency of days with abrupt changes of temperature in winter than in summer may not confuse our results. Moreover, in any such investigation as this the most important thing is to discover what conditions cause a change one way or the other in the deathrate.

In Table 3 line *A* indicates that during the months from April to September there were fifteen days when the average temperature of the day was 6° or more in excess of the average for the preceding day. On these days there was an average decline of 1.60 in the number of deaths from lobar pneumonia and 1.00 from broncho pneumonia. In line *B* it appears that on the fifty-four days when the temperature rose 2° to 5°, deaths from lobar pneumonia increased 0.61, while those from the bronchial form decreased 0.21. In both cases the change in the deathrate was less than in *A*, and the conditions of health were not so good. With a change of temperature amounting to 1° or less, line *C*, and with a drop of only 2° to 5°, line *D*, we still find an increase in the deathrate. With a drop of 6° or more, however, line *E*, the lobar type of pneumonia shows a diminution of 1.55 in the deaths per day and the bronchial type of 1.30. Turning to the winter months from October to March, we find conditions like those for the six warmer months except that while a marked rise of temperature is better than little or no change, it is by no means so favorable as a drop. Table 3 is highly important because it departs so far from our ordinary assumptions. It seems to indicate that at all seasons a drop of temperature has a stimulating effect and thereby diminishes the deathrate. This drop must of course be distinguished from continuous cold weather which has been shown above to be unfavorable. A rise of temperature also has a stimulating effect, but not so marked or consistent as that of a drop, while days when there is little or no change in the weather are the most unfavorable.

TABLE 3. *Effect of variability of the weather upon deaths from lobar and broncho pneumonia in New York City, from April, 1917, to March, 1918*

Note.—The figures in the body of the table indicate the average amount by which the number of deaths increased or decreased on the days having the indicated changes of mean temperature. The change in mean temperature is the amount by which the average temperature for a given 24 hours is above or below that of the preceding 24 hours.

	April–September			October–March		
	No. of days	Change in deaths from pneumonia		No. of days	Change in deaths from pneumonia	
		Lobar	Broncho		Lobar	Broncho
A. Rise of 6° or more	15	−1.60	−1.00	43	−0.40	0.26
B. Rise of 2°–5°	54	0.61	−0.21	44	1.07	0.64
C. Change of 1° or less	50	0.04	0.34	25	1.32	0.80
D. Drop of 2°–5°	43	0.28	0.26	28	1.07	−0.89
E. Drop of 6° or more	20	−1.55	−1.30	42	−1.64	−1.21

7. Confirmation of Present Investigation by Other Studies

The results thus far given are interesting and suggestive, but not conclusive. They are confirmed, however, by other lines of evidence. For example, nine million deaths from all sorts of diseases in the United States, France, and Italy during a period of fifteen years show a relation of temperature and humidity closely similar to that of lobar pneumonia.[4] They indicate that the health of Americans and Europeans is best when the average temperature for night and day is 64° F. and when the average humidity is 80 percent. In the same way a study of the weather on the day of death for 400,000 cases in New York City during a period of eight years shows with surprising clearness that a drop in temperature, as distinguished from steady cold, is beneficial at all seasons. A rise of temperature is in general unfavorable, and in this respect the results from the 400,000 deaths in 8 years differ from those based on the 9,600 deaths from pneumonia in a single year. Nevertheless, both sets of data combine to indicate that weather with frequent changes of considerable magnitude in both directions is distinctly better than weather when there are only slight changes.[5]

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[4] Huntington, Ellsworth, "World Power and Evolution," Yale University Press, 1919.

8. Why Variability is Helpful

During variable weather, even when patients are in well-warmed houses, a drop in temperature stimulates by causing a decrease of the unfavorably high temperature which regularly prevails in our houses. It also causes much more movement of the air than at times when the weather stays stationary from day to day. The harm that comes from a rise in temperature at any season except summer is not easy to explain. Apparently it arises largely from the fact that when the outside air grows warm the inside is apt to run up to high levels, even 75° or more, a condition which is decidedly harmful. If this is the case, however, the benefit that apparently comes to pneumonia patients from a rise in temperature is puzzling. Possibly, during the year used in this article, the increased humidity which usually prevails when the temperature rises overcame the bad effects of increased warmth. Moreover, judging by Table 1, it may be that pneumonia patients are favored by a temperature somewhat higher than that which is best for most ailments.[6]

9. Summary of Most Favorable Conditions

Another confirmation of the general truth of the results here set forth is found in a study of surgical cases in Boston for five years at one hospital and ten at another.[7]

Operations stand much the best chance of success if performed under the following conditions: (1) an average temperature of about 65°; (2) air of high relative humidity, provided it is not too warm; (3) a drop of temperature; and (4) a general condition of frequent and pronounced changes from day to day.

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[5] See "World Power and Evolution" or a summary entitled "The Interpretation of the Deathrate by Climographs," Modern Medicine, Vol. 1, No. 1, May, 1919.

[6] The effects upon man in health as well as in sickness of a variable as compared with a uniform climate offer a fruitful field for research. A uniform climate such as that of Western Europe and the Pacific Coast of the United States has generally been considered just as healthy, if not as stimulating, as the variable climate of the North Atlantic seaboard of America. Is not the greater heat of American houses, in winter, as compared with European houses, an attempt to overcome sudden changes of temperature? Just what physiological effects does the variability produce, and what the uniformity? What part is played by the various factors, temperature, air pressure and atmospheric electricity?—Editor.

[7] Huntington, Ellsworth, "Air Control and the Deathrate After Operations," Modern Medicine, Vol. 1, 1919, Sept. and Nov.

The essence of the whole matter is that the human body seems to have a decided optimum of temperature, humidity, and variability, and to be highly sensitive to any departure from the optimum. Different diseases apparently shift the optimum a little in one direction or another; surgical cases may require great humidity at the time of the operation and less later; lobar pneumonia may prefer a temperature a little higher than the optimum for persons in health; and other diseases may have their own peculiarities. Yet the general fact seems to be that in all diseases the departures of the air from the optimum are one of the greatest causes of death.

10. DATA FOR INVESTIGATION OF EPIDEMICS OF 1918

The next question which we shall consider is whether epidemic influenza and pneumonia show any climatic relationships at all similar to those of the endemic forms of the diseases. Nothing seems better established than that influenza epidemics may break out at any season, and that once started they run their course in spite of weather or climate. The only question is how far the conditions of the air may increase or diminish their severity. In the hope of getting some light on this problem, I have made use of the data stated in Table 4.

TABLE 4.[8] *Date Used in Investigation of Influenza Epidemic*

	Average Daily Change
1. *New York City.*	
A. Daily onset of cases of influenza, Sept. 18–Dec. 26, 1918	5.53
B.	
C. Daily deaths from influenza, Sept. 15–Nov. 25, 1918	15.20
D. Daily deaths from pneumonia, Sept. 14–Nov. 25, 1918	14.50
2. *Boston.*	
A. Cases of influenza reported daily, Oct. 4, 1918–Apr. 30, 1919	24.78
B. Cases of lobar pneumonia reported daily, Sept. 9, 1918–April 30, 1919	5.60
C. Daily deaths from influenza, Sept. 8, 1918–April 30, 1919	3.88
D. Daily deaths from pneumonia (all forms) Sept. 7, 1918–April 30, 1919	2.53

[8] The New York figures are more valuable than those of Boston for three reasons. (1) The number of cases is far larger than at Boston, although this is partly offset by the shorter period for which figures are available. (2) The relative humidity is the true mean of 24 hourly observations, and is not limited to a single observation morning or evening as at Boston. (3) Under heading *A* in the table the New York figures show the actual date when people began to feel seriously ill, whereas in Boston *A* and *B* represent merely the day when the physician was called, which of course introduces a certain error. Even in New York the records are far from ideal. As late as September, 1919, I could not procure a daily record except for the short period from September 14 to November 25, 1918. New York goes ahead of other cities, however, in preserving the report cards sent in by physicians, and in providing on them a space

In discussing the epidemic of 1918 I shall say nothing about mean temperature, for the period is too short to give any important results. On the basis of the evidence already cited, however, it seems safe to say that an epidemic in warm weather is much less severe than the same epidemic would be in cold weather.

In computing the effects of humidity and variability, I have reduced the exorbitant importance of the peak of the epidemic by using the *change* in the deathrate or case-rate from day to day, since that is what chiefly counts. Nevertheless the sudden onset of the epidemic is so obviously due to the virulence of the bacteria and not to the weather that it scarcely seems possible that any relationship should appear. Therefore, it is highly surprising to find that Tables 4 and 5 show strong signs of relationships like those found in the endemic forms of both influenza and pneumonia. In order to facilitate comparisons, the main figures in Tables 5 and 6 have been reduced to percentages of the average daily changes given in Table 4. Moreover, they are not the figures for a single day but the averages for the day on which a given weather condition occurred and for the succeeding day.

11. EFFECT OF VARIABLE WEATHER IN MITIGATING THE EPIDEMIC

TABLE 5. *Influenza and Pneumonia Compared with Changes in Temperature*
(Figures in parenthesis show number of days)

	Rise of 4° or more	Change of 3° or less	Drop of 4° or more
1. *New York.*			
A. Daily onset of influenza.......	21.2 (30)	10.3 (40)	−26.7 (23)*
B.	....	....	....
C. Daily deaths from influenza....	15.1 (21)	4.5 (31)	−28.2 (19)*
D. Daily deaths from pneumonia..	33.1 (21)	−1.4 (32)	−31.7 (19)*
2. *Boston.*			
A. Daily reports of influenza......	7.6 (58)	6.5 (75)	−19.2 (60)*
B. Daily reports of pneumonia....	11.3 (69)	−4.8 (83)	− 6.3 (64)*
C. Daily deaths from influenza....	−8.7 (74)	10.6 (91)	− 2.7 (69)
D. Daily deaths from pneumonia..	19.2 (77)	−1.7 (92)	−14.4 (66)*

We will take up variability before humidity, because it shows the more striking relationships. In Table 5 the first line means that in New York City during the period represented by *A* in Table 4 there were thirty days when the temperature averaged 4° or more above that of the preceding day. On those days and on the day immediately after there was an average daily increase of 21.1 percent in the number of new cases of influenza. In the next column it appears that on the 40 days with a change of 3° or less the deaths increased 10.3 percent, while the 23 days with a drop of 4° or more in temperature show an average decrease of 26.7 percent.

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to show how long the disease has been in progress. Not one physician in five, to be sure, fills in this space and the health authorities have not thought it worth tabulating. Hence in order to get the 3,095 random cases used in section A under New York it was necessary to wade through fifteen or twenty thousand cards.

The rest of Table 5 indicates that during the epidemic at New York the following conditions prevailed: (1) When the temperature rose, not only the onset of influenza, but also the deaths from both influenza and pneumonia increased notably; (2) When the temperature was stationary, the rate of onset rose somewhat, while the deathrate changed but little; (3) When the temperature dropped both the rate of onset and the deathrate diminished greatly. This does not mean that low temperature is favorable, but merely that a *drop* gives a healthful stimulus. If the temperature stays low it becomes harmful. In Boston the effect of variability on the epidemic was the same as in New York except that the deaths from influenzza depart somewhat from the rule and diminish when the temperature rose as well as when it fell.

Taken as a whole Table 5 is surprising. In spite of the suddenness with which the epidemic fell upon the country without apparent regard to the weather, six sets of data out of seven show precisely the same relation to variability as do the 400,000 deaths from disease in general during the 8 years described above. The seventh set shows a slightly different relation like that of deaths from both kinds of pneumonia under normal conditions as given in Table 3. All alike, however, indicate unequivocally that a drop in temperature is favorable, even though a continuance of low temperature does harm. Moreover, in the great majority of cases the combined effect of marked variations of temperature in both directions is better than the effect of uniformity. This would apparently be true in all cases were it not for the almost universal overheating of houses which goes to great extremes when the outdoor temperature is rising. In view of all these facts it seems reasonable to conclude that even in the throes of the worst epidemic the severity of the disease might be reduced appreciably by creating within our houses the mildly variable and fairly low temperatures which prevail when the outside air is growing cooler.

12. Effect of Humidity in Mitigating the Epidemic

Turning now to humidity, Table 6 shows that in New York City the lower the humidity the greater the number of cases of influenza and the greater the number of deaths from both influenza and pneumonia. The importance of moisture appears to be even greater than that of variability. At Boston, however, there is no such regularity. In general, as appears in the averages, the dry days are unfavorable, those with a moderate degree of humidity are on the whole the best, and the very moist days intermediate. Possibly this means that the damp east winds of Boston introduce a complicating factor which is not present in New York. In studying operations at Boston, the damp days appeared to be decidedly the most favorable for the operation, but a few days later, the days with a moderate humidity of 60 to 65 percent and a temperature of 65° were the best, while the dampest days were not so good. Extreme dryness was always the worst condition. It is quite possible, however, that in Boston the sudden onslaught of the influenza epidemic during a few days which happened to have a high relative humidity has masked the relationship which is so noticeable in the New York epidemic and also in ordinary pneumonia according both to Greenberg's studies and to the figures already given in this article. However that may be, it is noteworthy that low humidity appears in general to have a decidedly bad effect which is particularly marked in influenza. Thus with humidity, as with variability we find a relationship between the weather and the deathrate even in the midst of an epidemic. In spite of all the statements to the contrary, the virulence of epidemic influenza appears to be closely dependent on the weather.

TABLE 6. *Influenza and pneumonia compared with relative humidity*
(Figures in parenthesis show number of days)

	Rel. Hum. 0–55%	Rel. Hum. 56–80%	Rel. Hum. 81–100%
1. *New York.*			
A. Daily onset of influenza	16.8 (34)	− 5.9 (42)	− 9.9 (18)
B.	...	...	...
C. Daily deaths from influenza	47.8 (24)	−14.6 (33)	−57.0 (13)
D. Daily deaths from pneumonia	38.0 (25)	− 8.1 (34)	−48.2 (13)
Average	34.2	− 9.5	−38.4
2. *Boston.*			
A. Daily reports of influenza	1.3 (44)	5.3 (93)	−10.5 (56)
B. Daily reports of pneumonia	1.9 (47)	− 6.1 (104)	9.1 (62)
C. Daily deaths from influenza	45.0 (54)	−21.0 (111)	0.0 (69)
D. Daily deaths from pneumonia	−19.8 (54)	9.5 (112)	13.2 (69)
Average	7.1	− 3.1	3.0

13. THE IDEAL THERAPEUTIC CONDITION OF THE AIR.

The facts given in this article seem to indicate that proper air is of the greatest importance not only in ordinary influenza and pneumonia, but in the epidemic forms. Presumably the same is true of tuberculosis and other respiratory diseases, hence, the ideal method of restoring health in such ailments and of preventing their occurrence would seem to be to have the air (1) *variable in temperature,* (2) *fairly moist,* and (3) *not too warm.* The best way to appreciate the ideal along all of these lines is to consider a day in the spring or fall when the thermometer ranges from perhaps 58° at sunrise to 70° at noon, and when the air is moist enough to cause heavy dew at night, but is fairly dry at noon so that the average humidity for day and night together is about 80 percent. On such a day people can be comfortable either indoors with the windows wide open or outdoors. Little variations of temperature occur constantly, not only because of the changes due to the heating of the earth by the sun, but because a little breeze stirs the air, a cloud obscures the sun for ten or fifteen minutes, or a person passes from the sunlight to the shade.

Contrast this ideal condition with that of the ordinary house, office, or sickroom. Throughout the time when the furnace is running the windows are kept shut practically all the time except perhaps for a morning airing, the great aim being to keep the temperature not lower than 68° or more often 70°. The humidity is always low, dropping sometimes to 15 or 20 percent and rising as high as 60 percent only on the rarest days. When the outside air is damp, which usually means that it is also warm, the good effect of a sufficient supply of vapor is largely destroyed by keeping the windows shut and thus letting the rooms become too warm. The one time when conditions approach closely to the ideal is after a storm when the air is still fairly moist but does not contain the condensed vapor that makes things feel clammy, and when the temperature is falling in such a way that the thermometer inside the house keeps dropping and then rising as the furnace fire catches up with the outside change. Those are the days when few people contract influenza and other respiratory diseases, and when few die from them. The science of engineering has progressed sufficiently to give us any kind of air and any degree of change and humidity.[9] The question is simply whether physicians can make their patients, and especially those who nurse the patients, realize the tremendous benefit of air like that which makes October and May the healthiest times of the year. The hospital and the sickroom are the places for insisting on a reform which must some day spread to all parts of the community and which will do much to eradicate the respiratory diseases.

14. Fluctuations in Bacterial Activity

Coordinate with the variations in man's health in response to the environment there are great fluctuations in the activity of the bacteria of influenza. The origin of these fluctuations is one of the most important problems of biology. Rhythms or cycles of one kind and another prevail in many organisms. For example, Woodruff[10] has shown that in the infusorian known as paramoecium the rate of a sexual reproduction is subject to marked rhythms or cycles ranging in length from about 10 to 60 days. At the lowest point in the cycle there occurs a peculiar rearrangement of the cell structure, "endomixis." Although this is not sexual in any respect, since it concerns only a single cell, it seems to serve as a stimulant analagous to conjugation. Its occurrence is almost invariably followed by a marked increase in the rate of reproduction, as if the cells had been revivified. Then, after a decided maximum has been attained the stimulus wears off, and the reproductive rate again falls to a low ebb, after which a recurrence of endomixis initiates a new cycle.

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[9] For a discussion of the practical methods of accomplishing this see an article in The Modern Hospital, Chicago, April and May, 1920, entitled "The Purpose and Methods of Air Control in Hospitals."

[10] Woodruff, L. L., "Rhythms and endomixis in various races of *Paramoecium aurelia*," Biol. Bull. 33: pp. 51–56, 1917.

"The influence of general environmental conditions on the periodicity of endomixis in *Paramoecium aurelia*," Biol. Bull. 33: pp. 437–462, 1917.

The most striking feature of endomixis is the fact that it occurs simultaneously in unrelated races of paramoecium even when they are kept under markedly different conditions of temperature and nutrition. At the beginning of an experiment when the environmental conditions usually suffer a sudden change, the process is often hastened a little, thus showing that environment has something to do with the matter. Thereafter, however, all races or strains, no matter what their origin or their thermal and nutritional environment, fall into the same irregular cycles. One strain may be reproducing faster than another so that the number of generations from endomixis to endomixis may be different, but the *time* interval is the same for all strains. This suggests that an unknown factor of the environment is at work. Occasionally a strain fails to show endomixis when the process occurs in other strains, but the invariable result is death within a short time. Thus the revivifying internal rearrangement of the cells through endomixis seems to be essential to continued asexual reproduction of paramoecium. This simple animal has been found typical of life in general in so many and such important respects that we may well suspect it of being typical in this also.

If the endomixis of paramoecium really represents a widespread vital process, the cause of the cycles is of extreme importance. Among other things it may open the way to an understanding of the increase in virulence and presumably in the rate of reproduction, which characterizes certain types of bacteria during epidemics. Woodruff's work seems to demonstrate clearly that although nutrition and temperature cause marked cycles of their own, they are not the cause of the endomictic cycles now under consideration. This naturally raises the question whether or not the cycles are an innate function of life independent of environment. Their synchronism under highly varying conditions of temperature and nutrition seems against this. Moreover, the environmental causes are by no means exhausted. For example, far too little attention has been paid to atmospheric electricity. Over a decade ago Stone[11] showed conclusively that even a single spark or a very weak galvanic current in the nutrient media of bacteria, yeast, and other plants produces a marked acceleration in the rate of reproduction. A positive charge is more effective than a negative; too great a charge reduces vitality; and the right charge may increase the rate of reproduction a hundred-fold. We are led to inquire whether endomixis and its consequent cycles may not be partly due to electrical changes in the air. Such changes are well known. Everyone has seen electric sparks shooting from a cat's

[11] Stone, Geo. E., "Influence of Electricity in microorganisms," Bot. Gaz. vol. 48, pp. 359–379, 1919.

fur, from his own clothing, or from other sources. Before a thunderstorm, or while a snowstorm is brewing there are peculiar electrical conditions which change completely as soon as the storm breaks. Such conditions, acting either directly upon the nervous system or indirectly by stimulating the bacteria within the human body may be the cause of the headaches and general oppression which many people feel just before a storm. So subtle are the electrical conditions that they are able to penetrate the human body or to be effective within a thermostat. Thus in electricity we have an agency which is constantly varying and which has been proven experimentally to cause a remarkable stimulation of reproductive activity in bacteria and many other forms of life. Few phases of ecology offer a more fruitful field of study than endomixis and other cyclical phenomena on the one hand, and the effects of the less known environmental conditions such as electricity on the other.

Let us apply the foregoing reasoning to epidemics, especially to influenza. On a large scale an epidemic seems to represent the same thing that Woodruff's endomictic cycles and Stone's periods of electrical stimulation represent on a small scale. In both cases a single stimulus sometimes seems to increase the reproductive power of the paramoecia and bacteria for months. An epidemic may merely represent a similar increase in certain bacteria which cause disease. Suppose a bacterial form is residing in the throat. Its environment comprises chiefly three kinds of conditions: chemical, thermal, and electrical. All three may be altered by the condition of the air, for if dry cold air, for example, is inhaled it not only causes a slight reduction in the surface temperature of the throat, but by its drying action it may change the chemical environment. If this alters the relative rate of reproduction among the bacterial flora a further chemical change ensues. Suppose now that when a certain species of bacteria is favored by ideal conditions in the thermal and physico-chemical environment, it also receives an electrical stimulus or undergoes a process like endomixis under some other environmental control. In that case there will be a sudden increase in the rate of reproduction. This increased rate may last for months and thus produce an epidemic.

Another consideration may explain the occasional occurrence of epidemics of extraordinary virulence such as that of 1918. There is still much doubt as to just what form of bacteria causes influenza. This probably means that the disease is due to several bacteria, each contributing its own special disability. If such is the case, the most stimulating conditions for the various kinds are presumably different. Suppose that in quick succession there occur such environmental conditions that all the types of bacteria are stimulated. Then there will be an epidemic of unprecedented proportions. When all the types are at the height of their activity, the disease will assume the most virulent form. As it subsided the relative importance of different bacteria will vary and we shall have various forms of the disease. So, too, as the bacteria migrate from place to place the environmental conditions may stimulate or retard one or another type of bacteria with corresponding modifications in the disease.

All this is avowedly speculation, but it is controlled speculation. We are looking forward toward a future in which the science of ecology shall make its proper contribution to human welfare. Hence we must survey the whole field and must boldly project our ideas as far forward as possible. Searching on this side and on that by means of speculation and then by means of experiment, we may light upon principles which will revolutionize many phases of man's activity. In the realm of health there are clearly two great things to be done; one is to determine the optimum for mankind in respect to all the various features of the environment; the other is to determine in the same way the optimum for harmful bacteria. When that is done we can create the conditions that favor man, and destroy those that favor the bacteria. In this great work there is a part for every ecologist to play, whether he deals with plants, animals, or man; for what we now need most is a determination of the great principles on which the science is founded.

15. SUMMARY

1. The condition of the air has an important bearing on the diseases of the respiratory system. This paper presents an analysis of the relation between atmospheric conditions and the diseases of pneumonia and influenza in order to determine what conditions are best for patients suffering from these diseases.

2. Aside from epidemics, the deathrate from influenza as well as that from pneumonia, varies inversely with temperature: influenza begins with the frost, becomes severe when the temperature averages below freezing, reaches a maximum when the weather is coldest, and then declines.

3. Considering the daily deaths from pneumonia in relation to temperature and humidity, it is found that the deathrate from lobar pneumonia in New York City from April, 1917, to March, 1918, is less when the humidity is higher than when it is low. This applies to each of the eight temperature groups into which the year has been divided. At high temperatures the advantage of high humidity is less, and probably both extremely high and extremely low humidities are harmful. In bronchial pneumonia the effect of humidity appears to be less marked than in lobar pneumonia, although high relative humidity still shows an advantage over low humidity. Most significant is the fact that for outdoor temperatures of between 55° and 70° Fahrenheit the deathrate from lobar pneumonia remains at a rather uniform and comparatively low level so long as the relative humidity is not below 65 percent, but a drop of 20 percent from this humidity increases the deathrate

by at least one third. Much of the harm attributed to cold weather is probably due to injuriously low humidity in hospitals and houses. Data for influenza in relation to humidity are lacking, but since the deaths from influenza follow closely those from lobar pneumonia, it is probable that the relation is similar.

4. Variations in temperature cause a decrease in the deathrate from pneumonia. A drop in temperature, as distinguished from steady cold, is more favorable than a rise. Both a rise and a fall are more favorable than uniform temperature. Other data indicate that the health of Americans and Europeans is best with an average day and night temperature of 64° F. and relative humidity of 80 percent. The human body seems to have a decided optimum of temperature, humidity, and variability, and to be highly sensitive to any departure from this optimum.

5. Data on the influenza epidemic of 1918 also show that marked variations in temperature in both directions are more favorable than uniformity. The figures for New York show that the lower the humidity the greater the number of cases and deaths from influenza and pneumonia. In Boston extreme humidity, possibly due to damp east winds, is injurious.

6. The ideal air is (1) *variable in temperature,* (2) *fairly moist,* and (3) *not too warm,* air like that which makes October and May the healthiest time of year.

7. Man's health varies not only in response to the environment but with fluctuations in bacterial activity due to rhythms or cycles. Woodruff has found cycles of from 10 to 60 days in the infusorian paramoecium. A rearrangement of the cell structure, endomixis, increases the rate of asexual reproduction and initiates a cycle. Endomixis occurs simultaneously in various races of paramoecium, even when they are kept under different conditions of temperature and nutrition. The cause of endomixis is unknown, but it is suggested that atmospheric electricity may play an important part. Epidemics seem to represent the same thing as endomictic cycles and electric stimulation.

8. Further ecological work is required to determine (1) the optimum environment for mankind, and (2) the optimum for harmful bacteria.